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Comparative Study on Flexural Strength of Plain and Fibre Reinforced HVFA Concrete by Destructive and Non Destructive Techniques

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Abstract – *Cement concrete of all kind is one of the most consumed man made material on the earth and is of second order after water utilization. As per the recent data it is of the order 16 billion tone annually. Due to consumption of virgin material like cement the principal binder and precious natural material like stone aggregate, river sand concrete industry is not sustainable. In addition the durability parameter due to aggressive weather or exposure condition is also a challenging issue in this regards. Both these issues can be well addressed by minimum use of cement and hence less emission of* Co_2*, less consumption of energy in production of cement and optimum exploration of lime stone. Use of supplementary cementing material in form of industry byproduct or waste can be one of the best solutions for greening of the concrete and making concrete industry a sustainable one.*

This article deals with use of High Volume Fly Ash (HVFA) a waste from coal fired thermal power plant as supplementary cementing material and 12mm triangular shaped polyester fibre as secondary reinforcement to the conventional concrete. Article describes experimental investigations on properties of fresh concrete through compacting factor test and hardens concrete in terms of flexural strength at different age through destructive and non destructive test methods. The results show measurable gain by inclusion of polyester fibre over plain HVFA samples and significant gain beyond 28 days.

Keywords – *Compressive Strength, Fly ash, Fibre, Flexural Strength, Sustainability*

I. INTRODUCTION

Use of pulverized fly ash is the most effective and proven material as supplement to the Portland cement for manufacturing of concrete of different kinds and application. The pozzolanic action of fly ash due to microstructure and siliceous nature contribute to the strength and durability of concrete. Use of quality fly ash to the extent of 25-30% is encouraged since long and also standardize by different standards across the world. Replacement of the cement beyond 50% is one of the recent advances in concrete technology and popular as High Volume Fly Ash (HVFA) concrete. Sufficient work has been carried out since 1980 to study different parameters and aspect of HVFA concrete including mechanical and durability properties. Use of HVFA concrete has not become popular due to limitations like slower early strength development and poor resistance to flexural, impact and abrasion resistance for its application to wide range of construction practices. As part of research problem authors have explored inclusion of synthetic fibre to overcome the weaknesses and studied improvement in engineering and durability properties of HVFA concrete. Replacement of portland cement is made with class F fly ash at the rate of 50%, 55% and 60% by mass of cementing material. Mix design have been carried out through guide lines provided by P K Mehta and V M Malhotra and cross checked through European Method provided by Environmental Department. Design mix taken for experimental investigations are M25,M30,and M35 with 12 mm triangular shaped polyester fibre at rate of 0.15% and 0.25% by mass of cementing materials. This article describes study of engineering property by compressive and flexural strength measured through both destructive and non destructive approach and regression analysis is presented along with advantages through use of polyester fibre.

II. MATERIAL

2.1 Cement and Fly ash

53 grade Ordinary Portland cement conforming to BIS 12269-1999 was used. Class F fly ash from Wanakbori Thermal Power station, Gujarat conforming to BIS 3812-2003 was used in the present study. The scanning electron microscopic view of the fly ash is shown in the “Fig. 1.”

2.2 Admixtures

High range water reducing admixtures based on Naphthalene sulfonate was used for preparation of trial mix and letter for plain HVFA concrete samples. Latter for fibre reinforced HVFA samples Poly Carboxylate based super plasticizer was used.

2.3 Aggregates

Crushed stones of 20mm down and 10mm down were used as coarse aggregate. Local river sand was used as fine aggregate in the concrete mixtures.

2.4 Fiber

12mm size triangular-Trilobal shaped polyester fibre confirming to type III fibres under ASTM C: 1116 were used as a supplementary reinforcing material to enhance the mechanical properties of hardened concrete. The SEM view of fibre is shown in "Fig. 2. "

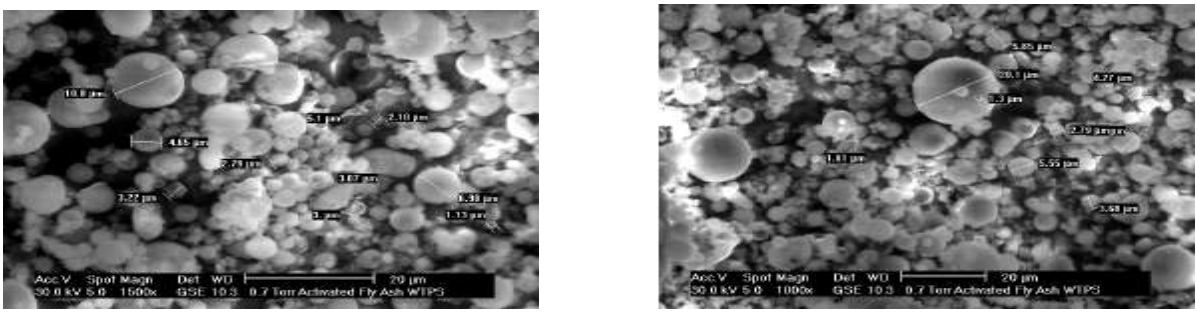


Fig. 1 SEM view of Flyash

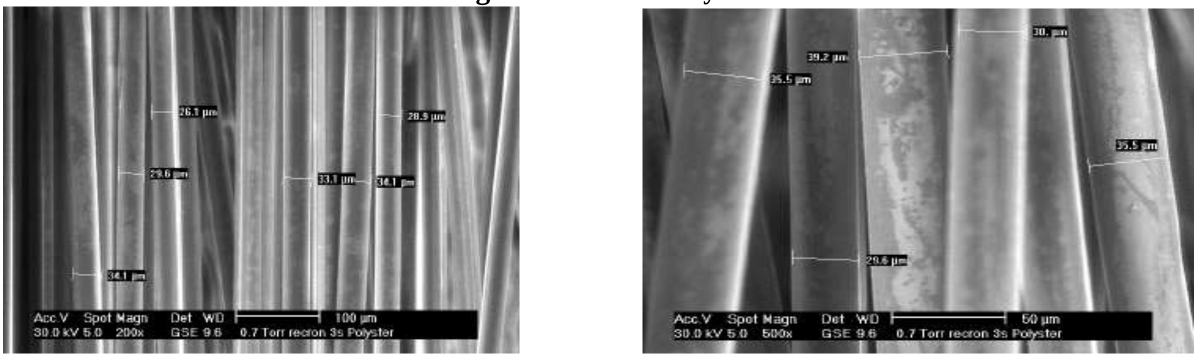


Fig. 2. SEM View of Polyester Fibre

III. EXPERIMENTAL SET UP

3.1 Compaction Factor Test

This test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height. The sample of concrete to be tested is placed in the upper hopper up to the brim. The trap-door is opened so that the concrete falls into the lower hopper. Then the trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder. In the case of a dry-mix, it is likely that the concrete may not fall on opening the trap-door. In such a case, a slight poking by a rod may be required to set the concrete in motion. This weight is known as "Weight of partially compacted concrete". The cylinder is emptied and then refilled with the concrete from the same sample in layers approximately 5 cm deep. The layers are heavily rammed or preferably vibrated so as to obtain full compaction. This weight is known as "Weight of fully compacted concrete". Comparative study of compaction factor is shown in Table 2, and graphically represented in "Fig.3"

$$The\,Compating\ Factor = \frac{Weight\,of\ \ partially\,compacted\ concrete}{Weight\,of\ \ fully\,compacted\ concrete}$$

3.2 Flexural Strength

3.2.1 Destructive Test

The test beam 100x100x500mm was symmetrically supported on two parallel steel rollers 38mm in diameter and the distance between the centers of the two rollers adjusted to 40 cm. The load is applied through one rollers mounted at the center point of the supporting span. The load is applied without shock and increased continuously at a rate of 180 kg/cm2/minute for the specimen. The load is increased till the specimen fails and the maximum load sustained is recorded. The position of crack is observed and measured. The flexural strength is expressed as the modulus of rupture fb as per the BIS 516. Observations and results recorded at 7,28 and 56 days are tabulated in Table 2.

3.2.2 Non Destructive Test (Ultrasonic Pulse Velocity Test)

The ultrasonic pulse velocity has been used on concrete for more than 60 years. **Powers** in 1938 and **Obert** in 1939 were the first to develop and extensively use the resonance frequency method. Since then, ultrasonic techniques have been used for the measurements of the various properties of concrete. Also, many international committees, specifications and standards adopted the ultrasonic pulse velocity methods for evaluation of concrete. The principle of the test is that the velocity of sound in a solid material, V ,is a function of the square root of the ratio of its modulus of elasticity, *E*, to its density, *d*, as given by the following equation:

$$V = f(\frac{gE}{d})^{1/2}$$

All the samples were tested as per BIS-13311 part-I and concrete quality was assured as per the standards given in Table 3. Graphical comparison of 28 days flexural strength is shown in Fig.4

Table 1. Velocity Criterion for Concrete Quality Grading

(As per IS - 13311-part 1)

Pulse velocity by cross-probing, Km/s	Concrete quality
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

IV. RESULTS AND DISCUSSION

4.1 Compaction Factor

Table 2 Comparative Study of Slump and Compaction Factor

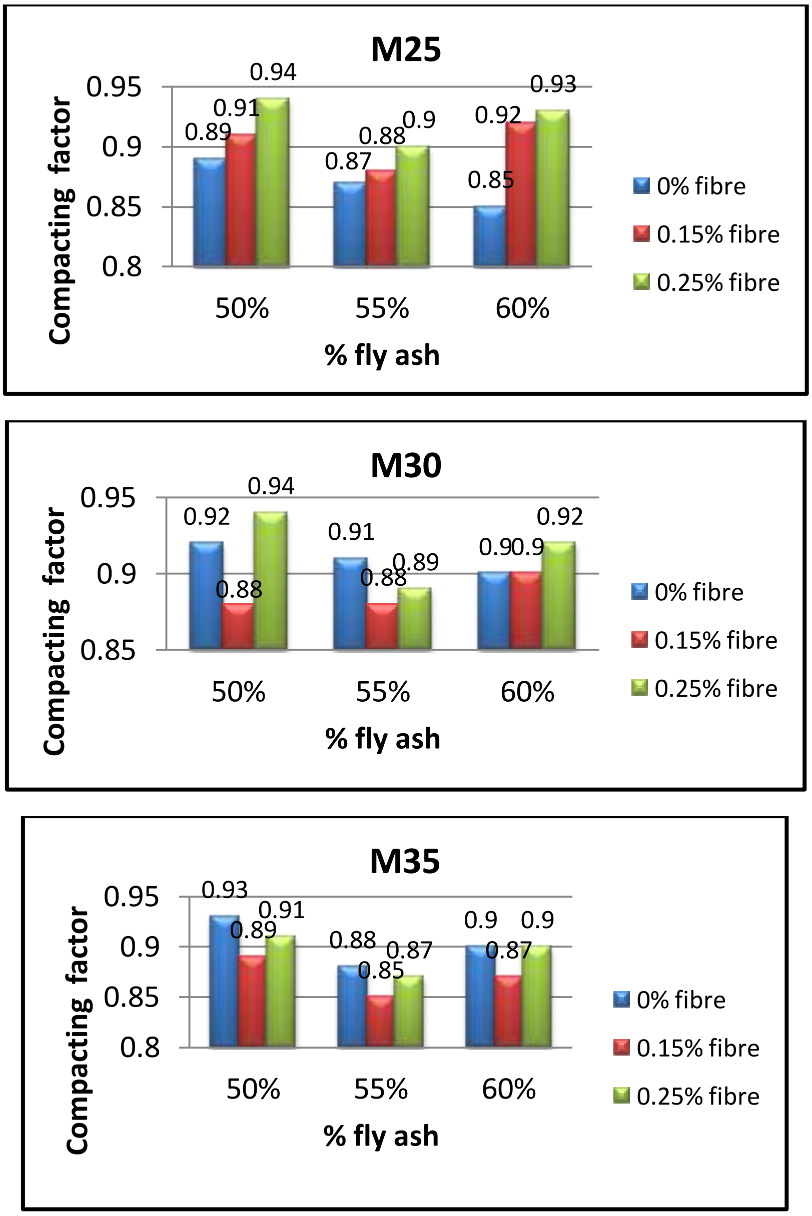
MIX	Fly Ash 50%								
	0.00% Fiber			0.15% Fiber			0.25% Fiber		
	w/c	S	CF	w/c	S	CF	w/c	S	CF
M25	0.30	92	0.89	0.4	95	0.91	0.44	100	0.94
M30	0.29	95	0.92	0.34	94	0.88	0.44	110	0.94
M35	0.28	98	0.93	0.34	90	0.89	0.34	95	0.91

MIX	Fly Ash 55 %								
	0.00% Fiber			0.15% Fiber			0.25% Fiber		
	w/c	S	CF	w/c	S	CF	w/c	S	CF
M25	0.28	95	0.87	0.32	100	0.88	0.32	94	0.9
M30	0.28	95	0.91	0.30	90	0.85	0.32	94	0.89
M35	0.26	90	0.88	0.28	85	0.85	0.28	85	0.87

MIX	Fly Ash 60%								
	0.00% Fiber			**0.15% Fiber**			**0.25% Fiber**		
	w/c	**S**	**CF**	**w/c**	**S**	**CF**	**w/c**	**S**	**CF**
M25	0.31	90	0.85	0.40	100	0.92	0.35	115	0.93
M30	0.30	100	0.90	0.36	90	0.9	0.32	100	0.92
M35	0.25	90	0.90	0.3	85	0.87	0.32	90	0.90

w/c = water to binder ration, S= slump at 60min retention in mm. CF = Compacting Factor

Fig.3 Compacting Factor Comparison



4.1.1 Discussion on slump value and compacting factor:

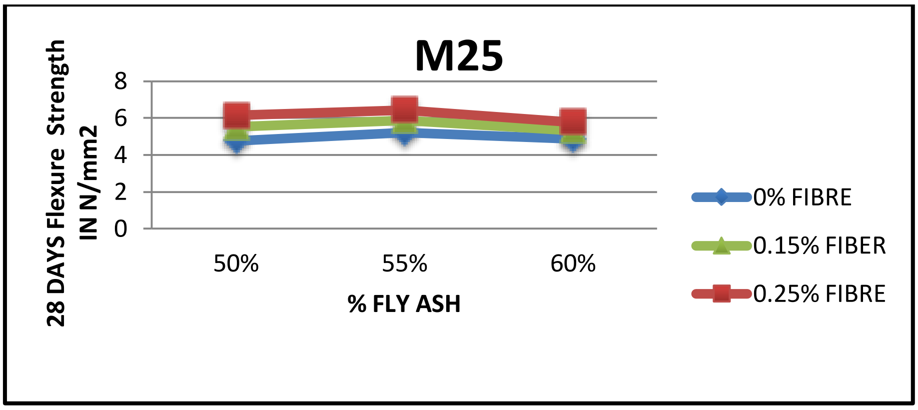
- Slump value ranging from 85mm to 115mm at 60min retention and compacting factor ranging from 0.85 to 0.94 which shows good workability with controlled water to binder ration 0.25 to 0.40 .
- Increase in fiber content does not have much effect on workability at 60min retention.
- For higher content of cementing material the water to binder ration is controlled by adjusting the dose of super plasticizers.

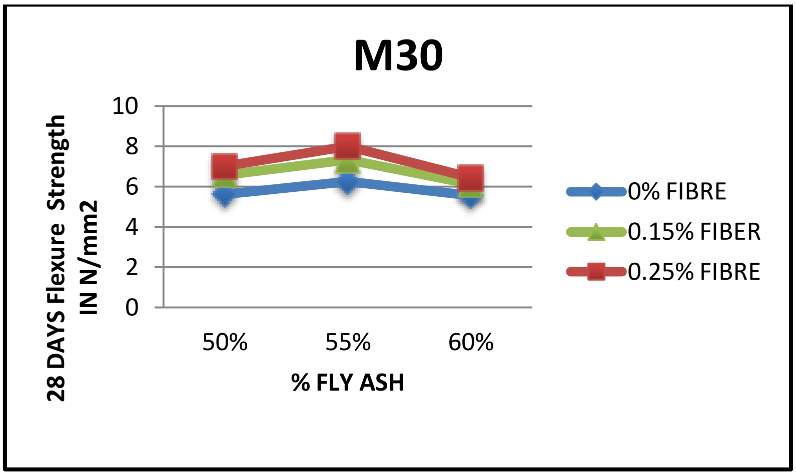
4.1 Flexural Strength

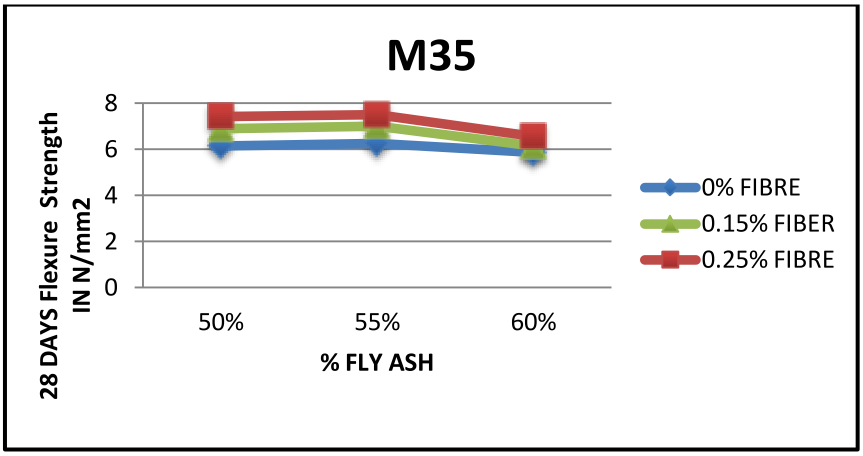
Table 3 Test result of Flexural Strength and Pulse Velocity

Mix	Days	0% fiber		0.15% fiber		0.25 % fiber	
		fb(MPa)	v(m/s)	fb(MPa)	v(m/s)	fb(MPa)	v(m/s)
50% fly ash							
M25	7	3.97	3983.32	4.05	3977.55	4.15	3910.65
	28	4.70	4270.33	4.96	4203.98	5.58	4180.20
	56	5.69	4375.02	6.02	4314.68	6.74	4285.47
M30	7	4.26	4133.54	4.46	4112.78	4.51	4085.94
	28	5.68	4371.68	6.28	4303.33	6.57	4238.11
	56	6.87	4457.95	7.39	4443.75	7.58	4351.01
M35	7	5.05	4214.04	5.62	4194.99	5.87	4120.37
	28	6.09	4487.51	6.62	4418.24	6.96	4400.21
	56	7.21	4580.74	7.71	4516.25	8.14	4481.61
55% fly ash							
M25	7	3.65	3900.93	3.80	3878.36	4.03	3839.94
	28	4.55	4254.17	4.86	4185.41	5.36	4107.29
	56	5.50	4348.41	5.96	4298.57	6.41	4218.87
M30	7	3.99	4065.45	4.23	4017.65	4.36	3987.67
	28	5.17	4338.41	5.26	4272.48	5.76	4237.44
	56	6.60	4396.93	6.79	4354.69	7.07	4328.76
M35	7	4.94	4198.83	5.34	4143.83	5.48	4035.60
	28	6.04	4440.68	6.41	4397.11	6.61	4366.56
	56	7.04	4535.22	6.79	4354.69	7.81	4443.09
60% fly ash							
M25	7	2.66	3880.22	3.04	3855.26	3.14	3836.07
	28	3.48	4134.91	3.91	4109.08	3.99	4059.09
	56	4.63	4308.95	5.25	4250.53	5.30	4212.62
M30	7	3.24	3975.00	3.39	3917.97	3.83	3883.44
	28	3.76	4203.37	4.35	4157.91	4.45	4121.65
	56	5.36	4359.73	5.62	4295.18	6.06	4223.90
M35	7	3.52	4145.82	3.75	4101.55	4.17	4003.29
	28	4.85	4380.83	5.18	4368.01	5.42	4320.75
	56	6.19	4479.40	6.60	4431.90	6.78	4394.71

Fig.4 Flexural Strength at 28 Days







4.2.1 Discussion on Flexural Strength and Pulse Velocity

- Increase in flexural strength at 7 days for 0.15% fiber is up to 14.39% and with 0.25% fiber is up to 18.4% compared to plain HVFAC.
- Increase in flexural strength at 28 days for 0.15% fiber is up to 15.6% and with 0.25% fiber is up to 18.3% compared to plain HVFAC.
- Increase in flexural strength at 56 days for 0.15% fiber is up to 13.32% and with 0.25% fiber is up to 18.3% compared to plain HVFAC.
- Gain of flexural strength from 7 days to 28 days for 50%, 55% and 60% of fly ash is up to 45.85%, 33% and 38.10% respectively.
- Gain of flexural strength from 28 days to 56 days for 50%, 55% and 60% of fly ash is up to 21.32%, 29.02% and 42.26% respectively.
- Pulse velocity decrease with increases fiber content up to 3.2%

V CONCLUSION

1. All the design mix with and without fibre found to be cohesive and homogenous with uniform matrix in terms of well dispersed fibre. No bleeding and segregation have been observed while casting of the different samples. Inclusion of fibre does not have significant effect on water to binder ratio , slump at 60 min. retention and compaction factor. All values for rheological parameters confirm the requirements of BIS-456 and workability.
2. Use of 12mm polyester shows marginal effect on increase in compressive strength at different ages but the increase is sufficient to achieve early age strength to HVFA concrete which is one of the drawbacks for potential use of HVFA concrete in different sectors on wide spectrum.
3. For plain HVFAC sample it is observed that all samples gain targeted strength at 28 days and notable increase in the strength continuous beyond 28 days. Increase in % of fly ash reduces % gain at different age of concrete.

4. Overall it is concluded that inclusion of fibre improves compressive strength of HVFAC by an average value of 9.75% to 15%, further with increasing age of concrete process of strength gain continues which leads to a major contribution in concrete life cycle analysis and durability.
5. All the sample with and without fibre gains minimum required flexure strength at 28 days as per BIS 456-2000 is 0.7√fck.
6. At 28 days % gain flexural strength with inclusion of 0.25% fibre is in order of 21% to 42%, 12% to 18% and 12% to 15% for different grade of concrete with fly ash content 50%, 55% and 60% respectively. Between age of concrete 28 days to 56 days average % gain is in order of 8% to 22%.% gain in flexural strength measured between 28 to 91 days ranges between 15% to 32% for plain HVFA, 14% to 23 % for 0.15% fibre inclusion and 10% to 21% for FRHVFAC with 0.25% fibre inclusion.
7. Different mix shows notable increase in post peak deflection ranging from 6.00% to 9.00% as compare to plain HVFA sample. This will add to ductility of concrete and hence better performance against vibration and cyclic load condition.
8. From UPV test results regression yields following equation for prediction of flexure strength at 28 days for measured UPV for different sample.

Fibre/Fly ash	**50%**	**55%**	**60%**
0%	f_b=0.004U-14.33	f_b=0.004U-13.34	f_b=0.002U-6.183
0.15%	f_b=0.004U-14.80	f_b=0.005U-16.16	f_b=0.001U-2.130
0.25%	f_b=0.003U-9.962	f_b=0.003U-9.265	f_b=0.002U-5.425

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